

BARYON NUMBER TRANSFER IN HIGH ENERGY hp COLLISIONS

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ABSTRACT

The process of baryon number transfer due to string junction propagation in rapidity is considered. It has a significant effect in the net baryon production in pp collisions at mid-rapidities and an even larger effect in the forward hemisphere in the cases of πp and γp interactions. The results of numerical calculations in the framework of the Quark-Gluon String Model are in reasonable agreement with the data with the same parameter values for different energies.

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1. INTRODUCTION

The Quark–Gluon String Model (QGSM) and the Dual Parton Model (DPM) are based on the Dual Topological Unitarization (DTU) and describe quite reasonably many features of high energy production processes, including the inclusive spectra of different secondary hadrons, their multiplicities, KNO–distributions, etc., both in hadron–nucleon and hadron–nucleus collisions [1, 2, 3, 4, 5]. High energy interactions are considered as proceeding via the exchange of one or several pomerons and all elastic and inelastic processes result from cutting through or between pomerons [6]. The possibility of exchanging a different number of pomerons introduces absorptive corrections to the cross sections which are in agreement with the experimental data on production of hadrons consisting of light quarks. Inclusive spectra of hadrons are related to the corresponding fragmentation functions of quarks and diquarks, which are constructed using the reggeon counting rules [7].

In the present paper we discuss the processes connected with the transfer of baryon charge over long rapidity distances. In the string models baryons are considered as configurations consisting of three strings attached to three valence quarks and connected in a point called "string junction" [8, 9]. Thus the string-junction has a nonperturbative origin in QCD.

It is very interesting to understand the role of the string-junction in the dynamics of high-energy hadronic interactions, in particular in the processes of baryon number transfer [10]. The important results were obtained in [11]. In this paper we prolong to study this problem. We find a set of the model parameters which can describe all experimental data concerning baryon number transfer. Feynman scaling violation for leading baryons is discussed. We also present the description of new experimental data.

2. INCLUSIVE SPECTRA OF SECONDARY HADRONS IN QGSM

As mentioned above, high energy hadron–nucleon and hadron–nucleus interactions are considered in the QGSM and in DPM as proceeding via the exchange of one or several pomerons. Each pomeron corresponds to a cylindrical diagram (see Fig. 1a), and thus, when cutting a pomeron two showers of secondaries are produced (Fig. 1b). The inclusive spectrum of secondaries is determined by the convolution of diquark, valence and sea quark distributions $u(x, n)$ in the incident particles and the fragmentation functions $G(z)$ of quarks and diquarks into secondary hadrons.

The diquark and quark distribution functions depend on the number n of cut pomerons in the considered diagram. In the following we use the formalism of QGSM.

In the case of a nucleon target the inclusive spectrum of a secondary hadron h has the form [1]:

$$\frac{x_E}{\sigma_{inel}} \frac{d\sigma}{dx} = \sum_{n=1}^{\infty} w_n \phi_n^h(x) \quad , \quad (1)$$

where x is the Feynman variable x_F and $x_E = 2E/\sqrt{s}$

The functions $\phi_n^h(x)$ determine the contribution of diagrams with n cut pomerons and w_n is the probability of this process. Here we neglect the contributions of diffraction dissociation processes which are comparatively small in most of the processes considered below. It can be accounted for separately [1, 2].

For pp collisions

$$\phi_{pp}^h(x) = f_{qq}^h(x_+, n)f_q^h(x_-, n) + f_q^h(x_+, n)f_{qq}^h(x_-, n) + 2(n-1)f_s^h(x_+, n)f_s^h(x_-, n) \quad , \quad (2)$$

$$x_{\pm} = \frac{1}{2}[\sqrt{4m_T^2/s + x^2} \pm x] \quad , \quad (3)$$

where the transverse mass of the produced hadron $m_T = \sqrt{m^2 + p_T^2}$ and f_{qq} , f_q and f_s correspond to the contributions of diquarks, valence and sea quarks respectively. They are determined by the convolution of the diquark and quark distributions with the fragmentation functions, e.g.,

$$f_q^h(x_+, n) = \int_{x_+}^1 u_q(x_1, n)G_q^h(x_+/x_1)dx_1 \quad . \quad (4)$$

In the case of a meson beam the diquark contributions in Eq. (2) should be changed by the contribution of valence antiquarks:

$$\phi_{\pi p}^h(x) = f_{\bar{q}}^h(x_+, n)f_q^h(x_-, n) + f_q^h(x_+, n)f_{\bar{q}}^h(x_-, n) + 2(n-1)f_s^h(x_+, n)f_s^h(x_-, n) \quad . \quad (5)$$

The diquark and quark distributions as well as the fragmentation functions are determined from Regge intercepts. Their expressions are given in Appendix 1 of [11]. In the present calculations we use the same function with only one exception.

The direct fragmentation of the initial baryon into the secondary one (nucleon or lambda/sigma hyperons) with conservation of the string junction can go via three different processes (Figs. 2a-2c). Obviously, in the case of Ξ production only two possibilities exist with string junction plus either one valence quark and two sea quarks or three sea quarks. In the case of production of a secondary baryon having no common quarks with the incident nucleons only the string junction without valence quarks can contribute (Fig. 2c).

All these contributions are determined by Eqs. similar to Eq. (4) with the corresponding fragmentation functions given by

$$G_{uu}^p = G_{ud}^p = a_N z^\beta [v_0 \varepsilon (1-z)^2 + v_q z^{2-\beta} (1-z) + v_{qq} z^{2.5-\beta}] , \quad (6)$$

$$G_{ud}^\Lambda = a_N z^\beta [v_0 \varepsilon (1-z)^2 + v_q z^{2-\beta} (1-z) + v_{qq} z^{2.5-\beta}] (1-z)^{\Delta\alpha} , \quad G_{uu}^\Lambda = (1-z) G_{ud}^\Lambda \quad (7)$$

$$G_{d,SJ}^{\Xi^-} = a_N z^\beta [v_0 \varepsilon (1-z)^2 + v_q z^{2-\beta} (1-z)] (1-z)^{2\Delta\alpha} , \quad G_{u,SJ}^{\Xi^-} = (1-z) G_{d,SJ}^{\Xi^-} , \quad (8)$$

$$G_{SJ}^\Omega = a_N v_0 \varepsilon z^\beta (1-z)^{2+3\Delta\alpha} . \quad (9)$$

The factor z^β is really $z^{1-\alpha_{SJ}}$. As for the factor $z^\beta z^{2-\beta}$ of the second term it is $2(\alpha_R - \alpha_B)$ [1]. For the third term we have added an extra factor $z^{1/2}$. The values v_0 , v_q and v_{qq} were taken from [11].

The secondary baryon consists of the SJ together with two valence and one sea quarks (Fig. 2a), one valence and two sea quarks (Fig. 2b) or three sea quarks (Fig. 2c). The fraction of the incident baryon energy carried by the secondary baryon decreases from a) to c), whereas the mean rapidity gap between the incident and secondary baryon increases. The diagram 2b has been used for the description of baryon number transfer in QGSM [1]. It describes also the fast pion production by a diquark.

The probability to find a comparatively slow SJ in the case of Fig. 2c can be estimated from the data on $\bar{p}p$ annihilation into mesons (see Figs. 1c, d). This probability is known experimentally only at comparatively small energies where it is proportional to $s^{\alpha_{SJ}-1}$ with $\alpha_{SJ} \sim 0.5$. However, it has been argued [12] that the annihilation cross section contains a small piece which is independent of s and thus $\alpha_{SJ} \sim 1$.

The main purpose of this paper is the determination of the contribution of the graph in Fig. 2c to the diquark fragmentation function. Its magnitude is proportional to a coefficient which will be denoted by ε .

Note that string-junction (as well as strings) has a nonperturbative origin in QCD and at present it is impossible to determine α_{SJ} from QCD theoretically. Thus we treat α_{SJ} , ε and a_N as phenomenological parameters, which should be determined from experimental data with the additional condition of baryon number conservation.

3. COMPARISON WITH THE DATA

The mechanism of the baryon charge transfer via SJ without valence quarks (Fig. 2c) was accounted for in previous paper [11], where the value $\alpha_{SJ} = 0.5$ was used. Practically all existing data at comparatively low energies ($\sqrt{s} \sim 15 \div 30$ GeV), were described with the value $\varepsilon = 0.05$. However, the ISR [13] data for the yields of protons and antiprotons separately, as well as their differences are described quite reasonably by QGSM with $\varepsilon = 0.2$. The same value of $\varepsilon = 0.2$ allows one to describe HERA [14] data on \bar{p}/p asymmetry. This confirm the result [15] that the \bar{p}/p asymmetry measured at HERA can be obtained by simple extrapolation of ISR data. It is necessary to note, that the systematic errors in [13] are of the order of 30 %, so the value $\varepsilon = 0.05$ can not be excluded. HERA data are preliminary and have rather large errors. However, now the

RHIC data on the \bar{p}/p ratios in pp collisions at $\sqrt{s} = 200$ GeV appear [16] and these data are in agreement with HERA data.

Some part of disagreement in the values of ε parameter at different energies can be connected with phase space effects. In the process of Fig. 2c, as a minimum, two additional mesons M should be produced in one of the strings, that can give an additional suppression [17] of the process Fig. 2c in comparison with, say Fig. 2a. However the 4 times difference in the values of ε parameter obtained in [11] in different energy regions seems to be too large for phase space suppression.

Another possibility to explain this difference is that the value of the intercept $\alpha_{SJ} = 0.5$ in [11] was taken too small. Really, the SJ contribution to the inclusive cross section of secondary baryon production at the rapidity distance Δy from the incident particle can be estimated as

$$d\sigma_B/dy \sim a_B \varepsilon e^{(\alpha_{SJ}-1)\Delta y}, \quad (10)$$

$a_B = a_N v_i$. So the increase of the effective value of ε with the energy, i.e. with Δy can be consider as a signal to increase the value of α_{SJ} .

In the presented paper we found the solution of the problem with the parameters

$$\alpha_{SJ} = 0.9, \quad \varepsilon = 0.024, \quad a_N = 1.33 \text{ (low energies)}, \quad a_N = 1.29 \text{ (high energies)}, \quad (11)$$

and the values v_i in Eqs. (6)-(9) were taken from quark combinatorics [11, 18]

The quality of the description of the experimental data with these parameters is practically the same as in [11]. As an example we present in Fig. 3 the inclusive spectra of secondary protons in pp collisions at lab. energies 100 and 175 GeV [19].

In Fig. 4 we show the data [20] on the asymmetry of strange baryons produced in π^- interactions* at 500 GeV/c. The asymmetry is determined as

$$A(B/\bar{B}) = \frac{N_B - N_{\bar{B}}}{N_B + N_{\bar{B}}} \quad (12)$$

for each x_F bin.

The theoretical curves for the data on all asymmetries calculated with parameters (11) are in reasonable agreement with the data. Sometimes this agreement is even better than in [11].

In the case of $\Omega/\bar{\Omega}$ production we predict a non-zero asymmetry in agreement with experimental data. Let us note that the last asymmetry is absent, say, in the naive quark model because Ω and $\bar{\Omega}$ have no common valence quarks with the incident particles.

*These data were obtained from pion interactions on a nuclear target where different materials were used in a very complicated geometry. We assume that the nuclear effects are small in the asymmetry ratio (12), and compare the pion-nucleus data with calculations for π^-p collisions.

Preliminary data on p/\bar{p} asymmetry in ep collisions at HERA were presented by the H1 Collaboration [14]. Here the asymmetry is defined as

$$A_B = 2 \frac{N_p - N_{\bar{p}}}{N_p + N_{\bar{p}}}, \quad (13)$$

i.e. with an additional factor 2 in comparison with Eq. (12). The experimental value of A_B is equal to $8.0 \pm 1.0 \pm 2.5$ % [14] for secondary baryons produced at $x_F \sim 0.04$ in the γp c.m. frame. In QGSM the hadron structure of photon is considered as $(\pi^+ + \pi^-)/2$ [21]. Such approach with parameters (11) leads to the value $A_B = 9.9$ %, in agreement with the data. The experimental value A_B was predicted in [22] using $\alpha_{SJ} = 1$ that is rather close to our choice (11).

The baryon charge transferred to large rapidity distances can be determined by integration of Eq. (10), so it is of the order of

$$\langle n_B \rangle \sim a_B \varepsilon / (1 - \alpha_{SJ}). \quad (14)$$

It is clear that the value $\alpha_{SJ} = 1$ should be excluded due to the violation of baryon number conservation at very high energies. At the same time the values of α_{SJ} very close to unity are possible. If the essential part of the initial baryon charge is transferred to large rapidity distances, the altitude of secondary baryon spectra in the proton fragmentation region (large x_F) should be decreased. This leads to violation [23] of Feynman scaling at very high energies. For example, we predict decrease of the secondary neutron multiplicity with $x_F > 0.28$ from 0.324 to 0.27 for energy region $\sqrt{s} = 20 \div 200$ GeV. The experimental estimation of this effect [24] is significantly larger, about two times.

The RHIC pp data [16] on the ratio of \bar{p}/p at low values of c.m. rapidity also are described reasonably with parameters (11) as one can see in Fig. 5.

Some our predictions at $\sqrt{s} = 200$ GeV for the antihyperon/hyperon production asymmetries in γp and \bar{B}/B ratios in pp collisions are presented in Table 1.

Table 1

The predicted values of the antihyperon/hyperon production asymmetries Eq. (13) in γp collisions and \bar{B}/B ratios in pp collisions, both at $\sqrt{s} = 200$ GeV.

Hyperons	A_B	B/\bar{B}
$\Lambda, \bar{\Lambda}$	10.8 %	0.77
$\Xi, \bar{\Xi}$	6.5 %	0.82
$\Omega, \bar{\Omega}$	12.0 %	0.81

5. CONCLUSIONS

We presented the role of string junction diffusion for the baryon charge transfer over large rapidity distances. Without this contribution shown in Fig. 2c the data for hyperon/antihyperon asymmetries (Fig. 4), proton/antiproton asymmetry [14] and \bar{p}/p ratios at RHIC (dashed curve in Fig. 5) are in total disagreement with the data.

It is necessary to note that value of ε parameter in (11) was taken from the normalization to one experimental point, parameter α_{SJ} was found from energy (or rapidity) dependence of the observed effects and the value a_N was calculated from the condition of baryon number conservation. The results of calculations for another processes which are also sensitive to string junction diffusion of baryon charge are practically the same as in [11], so we do not present them. It is necessary to note that the existing experimental data are not enough for determination of the SJ parameters with the needed accuracy.

This paper was supported by DFG grant GZ: 436 RUS 113/771/1-2 and, in part, by grants RSGSS-1124.2003.2 and PDD (CP) PST.CLG980287.

Figure Captions

Fig. 1. Cylindrical diagram corresponding to the one-pomeron exchange contribution to elastic $\bar{p}p$ scattering (a) and its cut which determines the contribution to inelastic $\bar{p}p$ cross section (b) (string junction is indicated by a dashed line). The diagram for elastic $\bar{p}p$ -scattering with SJ exchange in the t -channel (c) and its s -channel discontinuity (d) which determines the contribution to annihilation $\bar{p}p$ cross section.

Fig. 2. Three different possibilities of secondary baryon production in pp interactions via diquark d fragmentation: string junction together with two valence and one sea quarks (a), together with one valence and two sea quarks (b), together with three sea quarks (c).

Fig. 3. The spectra of secondary protons (a) in pp collisions at 100, 175 GeV/c [19] and their description by QGSM.

Fig. 4. The asymmetries of secondary $\Lambda/\bar{\Lambda}$ (a), Ξ^-/Ξ^+ (b) and $\Omega/\bar{\Omega}$ (c) in π^-p collisions at 500 GeV/c [20] and its description by QGSM.

Fig. 5. The ratios of secondary antiproton/proton production in pp interactions at $\sqrt{s} = 200$ GeV (points and solid curve). The calculated result with $\varepsilon = 0$ is shown by dashed curve.

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